Some geometric parameters impact to the static characteristics of a pilot operated pressure relief valves

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Some geometric parameters impact to the static characteristics of a pilot operated pressure relief valves: *Some geometric parameters impact to the static characteristics of pilot operated pressure relief valves were investigated in this paper. It has been shown that with introducing a compensating control piston in the pilot line of the conventional design of pressure relief valve improves the static characteristic at the beginning of the opening of the valve i.e. decrease the pressure difference between opening of the pilot valve and the main valve. Also, better static characteristic is achieved if the area of the main valve seat is equal with the main valve poppet area, i.e. when the factor φ is decreasing.*

***Keywords**: Static characteristic, pressure relief valve, pressure override, flow, pressure,*

INTRODUCTION

The function of the pressure relief valve in any hydraulic system is to limit the system pressure at previously adjusted value. Main feature of the static characteristic of the pressure relief valves is its slope, i.e. increasing of the adjusted value of the pressure when increasing the flow through the valve. This means that there is an error in the static characteristic. As an example, at fig.1 schematic layout of the static characteristic of direct operated and pilot operated pressure relief valve is shown [3].

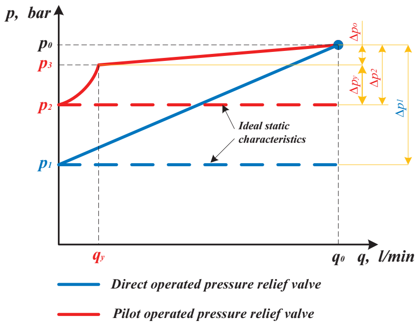


Fig.1. Static characteristic of pressure relief valves

With blue color a static characteristic of direct operated pressure relief valve is presented. The valve opens at pressure value p_1 and with increasing of the inlet flow through the valve the pressure increasing up to p_0 when the entire flow q_0 passes through the valve. As can be seen, there is a deviation from the ideal static characteristic and at flow q_0 the error of the static characteristic is $\Delta p_1 = p_0 - p_1$. This error is caused by the deformation of the spring and the hydrodynamic force of the streaming flow [1].

At the static characteristic of pilot operated pressure relief valves, two zones are noted: the first one for inlet flow from *0* to q_y and the second one for inlet flow from q_y to maximal flow q_0. Increasing the system pressure in the hydraulic circuit, at pressure value p_2 the pilot valve opens and a little amount of pilot oil flows through it. The main valve is still closed. The pressure in front of the valve continues to increase parabolic until the pressure value p_3 when the main valve opens. At the second zone the pressure increases linearly from p_3 until p_0 as inlet flow increasing up to the maximal value q_0. Total error of the valve is sum of the error of the pilot valve $\Delta p_y = p_3 - p_2$ and of the error of the main valve $\Delta p_0 = p_0 - p_3$ i.e. $\Delta p_2 = \Delta p_y + \Delta p_0$. Comparing the static characteristics of direct operated and pilot operated pressure relief valve it can be seen that the accuracy of the adjusted pressure is with pilot operated pressure relief valve, i.e. $\Delta p_2 \ll \Delta p_1$. A disadvantage of the static characteristic of pilot operated pressure relief valve is pressure difference between opening of the pilot and the main valve at first zone of the static characteristic i.e. error of the static characteristic at the beginning of opening of the valve. This error increases energy loss and converted it into heat which leads to increasing of the temperature of the oil and decreasing the efficiency coefficient of the entire hydraulic system [2].

In this paper a comparison of theoretical and experimental static characteristic of direct operated and pilot operated pressure relief valve is presented. Few methods of improving of the static characteristic of pilot operated pressure relief valves are outline.

Theoretical static characteristic of a pilot operated pressure relief valves

Functional diagram of the investigated pilot operated pressure relief valve is shown on fig.2.

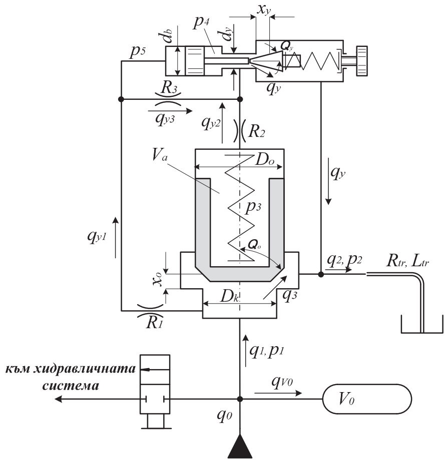


Fig.2. The functional diagram of the valve

The static characteristics of the pilot operated pressure relief valves are described with following equations:

- *Flow equation across the pilot valve*

$$q_y = \mu_y \cdot d_y \cdot \pi \cdot x_y \cdot \sin\theta_y \cdot \sqrt{\frac{2}{\rho} \cdot p_{4,2}} \qquad (1)$$

where: q_y - the flow across the pilot valve; μ_y - the flow coefficient of the pilot valve; d_y - the seat diameter of the pilot valve; x_y - the displacement of the closing element of the pilot valve; θ_y - the angle of flowing of the oil at the pilot valve, ρ - the density of the oil; $p_{4,2} = p_4 - p_2$ - the pressure drop in the pilot valve.

- *Balance of forces acting on the closing element of the pilot valve*

$$c_y \cdot (h_y + x_y) = p_{4,2} \cdot A_y + p_{5,4} \cdot A_b - r_y \cdot x_y \cdot p_{4,2}$$

or

$$x_y = \frac{p_{4,2} \cdot A_y + p_{5,4} \cdot A_b - c_y \cdot h_y}{c_y + r_y \cdot p_{4,2}} \qquad (2)$$

where: A_y - the area of the seat of the pilot valve; c_y - the spring constant of the pilot valve; h_y - the previous deformation of the spring of the pilot valve; r_y - the hydrodynamic force coefficient of the pilot valve; A_b - the area of the compensating control piston; d_b-diameter of the compensating control piston; $p_{5,4}$ - pressure drop in the compensating control piston orifice.

If we solve the equations (1) and (2), the static characteristic of the pilot valve will be obtained:

$$q_y = \mu_y \cdot d_y \cdot \pi \cdot \sin\theta_y \cdot \sqrt{\frac{2}{\rho} \cdot p_{4,2}} \cdot \frac{p_{4,2} \cdot A_y + p_{5,4} \cdot A_b - c_y \cdot h_y}{c_y + r_y \cdot p_{4,2}} \qquad (3)$$

- *Pressure drop at the fixed orifices*

$$p_{1,4} = R_l \cdot q_y + R_m \cdot q_y^2 \qquad (4)$$

where: $p_{1,4} = p_1 - p_4$ - the pressure drop at the pilot chain, $R_l = R_{1l} + R_{3l}$ - the linear hydraulic resistance in the orifices R_1 and R_3; $R_m = R_{1m} + R_{3m}$ - the local quadratic resistance in the orifices R_1 and R_3;

- *Pressure drop at the main valve*

$$p_{1,2} = p_{1,4} + p_{4,2} \qquad (5)$$

where: $p_{1,2} = p_1 - p_2$ - the pressure drop at the main valve

➢ *Balance of forces acting on the poppet of the main valve*

$p_{1,4} \cdot A_k - p_{1,2} \cdot \Delta A = c_o \cdot (h_o + x_o) + r_o \cdot x_o \cdot p_{1,2}$

or

$$x_o = \frac{p_{1,4} \cdot A_k - p_{1,2} \cdot \Delta A - c_o \cdot h_o}{c_o + r_o \cdot p_{1,2}} \qquad (6)$$

where: A_k - the area of the closing element of the main valve; ΔA - the unbalanced area at the closing element of the main valve; $\varphi = \Delta A / A_k$ - geometric parameter of the valve; h_o – the previous deformation of the spring of the main valve; x_o - the displacement of the closing element of the main valve; r_o - the hydro-dynamic force coefficient of the main valve; μ_o- the flow coefficient of the main valve; D_k - the diameter of the closing element of the main valve; θ_o - the angle of flowing of the oil at the pilot valve.

➢ *Flow across the main valve*

$$q_3 = \mu_o \cdot D_k \cdot \pi \cdot x_o \cdot \sin\theta_o \cdot \sqrt{\frac{2}{\rho} \cdot p_{1,2}} \qquad (7)$$

where: q_3 - the flow across the main valve.

➢ *Flow through pilot chain*

$$q_1 = q_3 + q_y \qquad (8)$$

The static characteristics of the pilot operated pressure relief valves are fully described by the equation (1) to (8) . From equations (1) – (8) theoretically can be expressing the pilot flow and the difference between the pressure of opening of the pilot valve and the main valve if there is built-in compensating control piston [5]:

$$(q_y)_{oo} = \sqrt{\frac{p_{1,oo} \cdot \varphi + \frac{c_o \cdot h_o}{A_k} - (R_{1l} + R_{3l}) \cdot (q_y)_{oo}}{R_{1m} + R_{3m}}}$$

$$p_{1,oo} = \frac{1}{1-\varphi}\left(\begin{array}{l} p_{1,oy} + \frac{c_o \cdot h_o}{A_k} + \frac{x_y \cdot (c_y + r_y \cdot p_{4,o})}{A_y} - \\ - \frac{A_b}{A_y} \cdot (R_{3l} \cdot (q_y)_{oo} + R_{3m} \cdot (q_y)_{oo}{}^2) \end{array} \right)$$

The last equation shows that the pressure difference between pilot and main valve opening is lower when there is built-in compensating control piston in the pilot valve. With increasing the diameter of compensating control piston d_b, i.e. the area of the compensating piston, the last part of the equation is getting greater and the pressure difference is getting lower. The effect of reducing the difference between the pressure of opening of the pilot and the main valve experimentally is shown on fig.7.

High impact to the pressure difference of opening of the main valve and the pilot valve has the factor φ. If φ is greater, also $p_{1,oo}$ is getting greater and vice versa.

With linearization of the equations (1) – (8) around the steady state values of pressure p_0 and flow q_0, the slope of the static characteristic can be express as [Dimitrov 2011]:

$$k_{st} = \frac{c_o + r_o \cdot (p_{1,2})_0}{\mu_o \cdot \pi \cdot D_o \cdot \sin\theta_o \sqrt{\frac{2}{\rho} \cdot (p_{1,2})_0} \cdot A_k} \cdot \left[1 + \frac{k_{st,y}}{(R_{1l} + R_{3l}) + (R_{1m} + R_{3m}) \cdot 2 \cdot q_{y,0}}\right] \qquad (9)$$

where the slope of the static characteristic of the pilot valve is expressed as:

$$k_{st.y} = \frac{c_y + r_y \cdot (p_{4,2})_0}{\mu_y \cdot \pi \cdot d_y \cdot \sin\theta_y \sqrt{\frac{2}{\rho} \cdot (p_{4,2})_0} \cdot A_y} - (R_{3t} + 2 \cdot q_{y,0} \cdot R_{3m}) \cdot \frac{A_b}{A_y} \tag{10}$$

EXPERIMENTAL STATIC CHARACTERISTICS

The subject of investigation was *Denison* pressure relief valve type *R4V 06*, shown on fig.3 [4] – with and without compensating control piston. The parameters of the valve are: $d_y = 5\ mm$, $c_y = 250\ \frac{N}{mm}$, $d_b = 5.5\ mm$, $d_{dr1} = d_{dr3} = 0.8\ mm$, $d_{dr2} = 0.6\ mm$, $l_{dr1} = l_{dr2} = l_{dr3} = 1\ mm$, $D_k = 28.5\ mm$, $D_o = 28\ mm$, $c_o = 7\ \frac{N}{mm}$, $h_o = 16.5\ mm$.

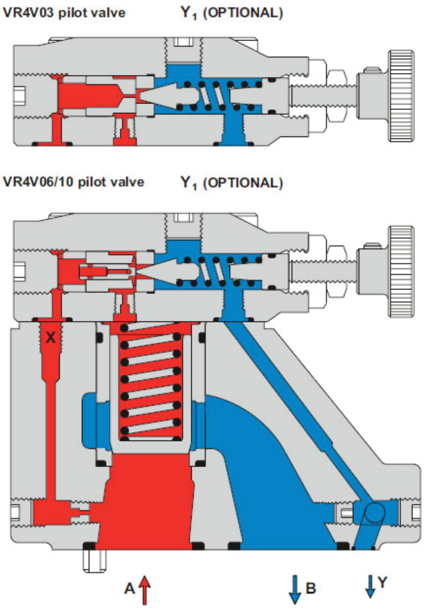


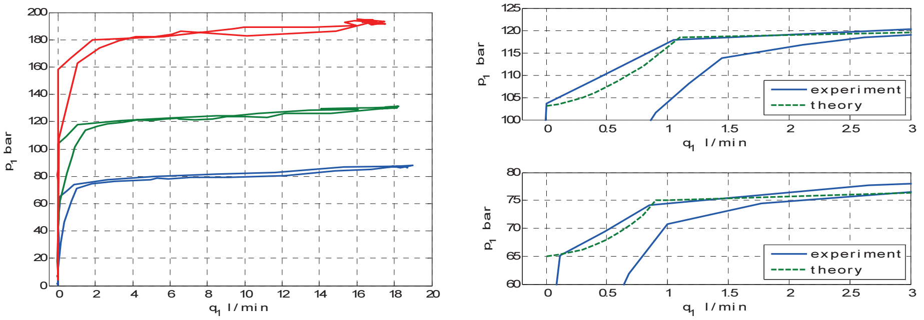
Fig.3. The investigated pressure relief valve

As a comparison, two other pilot operated pressure relief valves were investigated, as well.

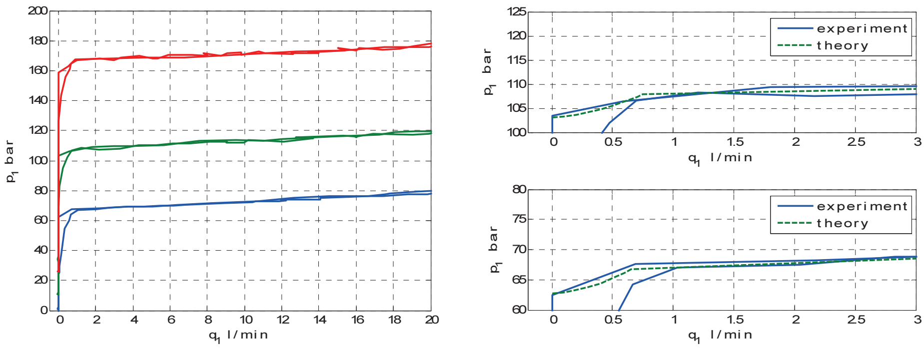
Theoretical and experimental static characteristic of the investigated pilot operated pressure relief valve are presented on fig.4.

At the diagrams on fig. 4 can be seen that pressure difference between opening of the pilot and the main valve is higher for the valve without compensating piston and it is decrease with the increasing of the compensating control piston diameter d_b. Also, the pilot oil flow and the pressure-flow coefficient of the valve are decreasing with increasing of the compensating control piston diameter d_b and higher without compensating control piston.

As a comparison, two other pilot operated pressure relief valves were investigated, as well.



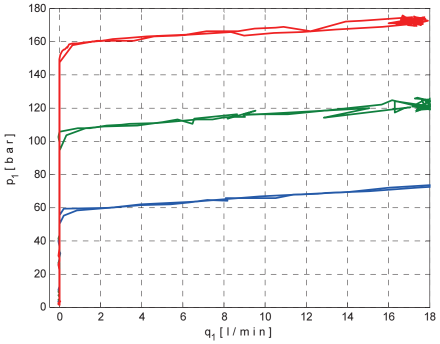
a-without compensating control piston



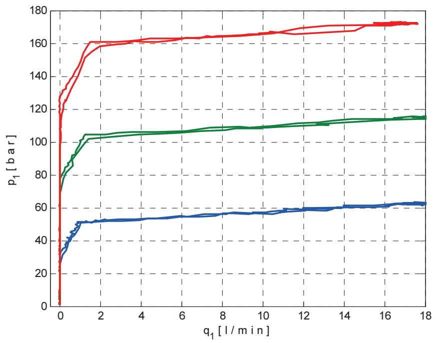
b-with compensating control piston d_b=6.5 mm

Fig.4. The theoretical and experimental static characteristic of the pilot operated PRV-Denison

At fig.5 the static characteristic of Rexroth design of PRV is presented. This valve is with factor $\varphi = 0$ and it is noticeable that $p_{1,\infty}$ is lower than the static characteristic of Freeway design valve which has factor φ greater.



a-Rexroth type pilot operated PRV



b-Freeway type pilot operated PRV

Fig.5. Experimental static characteristics of other PRV

CONCLUSION

In these paper static characteristics of pilot operated pressure relief valves depending on some geometric parameters of the valve is studied. First Denison PRV was investigated where experimentally and theoretically was proved the fact that introducing the control piston in the pilot line the static characteristic is improved at the beginning of opening of the valve i.e. the pressure difference between opening of the pilot and the main valve is lower. Experimentally has been shown that static characteristic can be improved also with decreasing the value of factor φ. Two types of pilot operated pressure relief valves have been investigated and has been proved that the geometric parameter φ has significant influence to the quality of the static characteristics of the pilot operated pressure relief valves.

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The report is reviewed.